THE LEAKY SURFACE WAVE IN SiO_2/49° Y-X $LiNbO_3$ STRUCTURE*

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ABSTRACT

In this paper the velocity, attenuation and dispersion curve of LSW, the electro-mechanical coupling coefficient K^2 versus film thickness normalized to wave length (kh) and TCD versus kh, TCD versus temperature T for SiO_2/49° Y-X $LiNbO_3$ structure with different boundary conditions have been calculated. These results show that within the range 0<kh<0.5 the attenuation of LSW is very small, near to 0. Under different boundary conditions, SiO_2 of suitable film thickness (kh=1.53,1.37,2.0) can all get zero TCD, whereas K^2 versus kh will be different. When IDT are in the interface, K^2 will increase as kh increases and has a maximum. The maximum K^2 is 15% i.e., about 1.08 times as large as K^2_0 which is the electro-mechanical coupling coefficient of zero film thickness.

INTRODUCTION

Since the SAW devices come into exist, they have been developed quickly and used widely in both military and consumer electronic equipment, such as RADAR, communication, and TV set due to their strong signal processing functions. In process of their development, people are more and more interested in the characteristics of SAW materials because the performance of SAW devices are greatly related to them. Usually the following characteristics are desired: 1) large electro-mechanical coupling coefficient, which will lead to lower loss. 2) small temperature coefficient of delay which will lead to better temperature stability. 3) fast propagation velocity, so one can get higher frequency devices within existing photolithograph resolution. In order to seek materials with these characteristics, a lot of efforts have been made. A relatively successful one is to search for new propagation modes. It has been found that electro-mechanical coupling coefficient K^2 of some leaky wave modes can be as large as 17-18%, which is much higher than 5.5% of the Rayleigh mode in 128° Y-X $LiNbO_3$. For example people have found such leaky modes in Y-cut $LiNbO_3$ [1], Y-41° $LiNbO_3$ [2] and 49° Y-X $LiNbO_3$. The last one has the highest K^2 and the lowest attenuation.

Since the 49° Y-X $LiNbO_3$ has a high temperature coefficient of delay (TCD), about 85 ppm, its application is limited. To overcome this shortcomings, we deposit a SiO_2 film on 49° Y-X $LiNbO_3$ to compensate its TCD. Previously, T.E.Parker etal. [3,4] improved TCD of Y-Z $LiTaO_3$ and Y-Z $LiNbO_3$ by using SiO_2/Y-Z $LiTaO_3$ and SiO_2/Y-Z $LiNbO_3$ structures. In their papers, excellent temperature coefficients for these structures are reported. But rather large film thickness (about kh=3) is needed and propagation loss is large. K.Yamanouchi etal. also have studied Si/36° Y-X $LiTaO_3$, SiO_2/126° Y-X $LiTaO_3$, SiO_2/131° Y-X $LiNbO_3$ structures [5,6], and have obtained similar results. Recently, K.Yamanouchi and J.J.Yin [7] have presented the propagation characteristics of SiO_2/128° Y-X $LiNbO_3$ structure respectively. They get better results.

In this paper, we have calculated the leaky wave characteristics and TCD of SiO_2/49° Y-X $LiNbO_3$ structure.

THEORETICAL CALCULATION

The geometry for leaky wave propagation in layered structure and coordinate system are shown in fig1, where h is the thickness of film, X is the propagation direction, Z is the normal direction to interface. From the leaky wave definition, the partial wave of leaky wave can be expressed as:

$$U_j = A_j \exp[ikbz] \exp[ik(1+i\delta)x] \exp[-i\omega t]$$
$$\Phi = A_4 \exp[ikbz] \exp[ik(1+i\delta)x] \exp[-i\omega t]$$
$$j=1,2,3$$

Where, δ is the propagation attenuation, A_j is the amplitude of the wave, Φ is electric potential. Using Christoffel equation and two-dimension Powell methods, we calculated velocity V and attenuation δ under different boundary conditions. Fig2-fig7 present the dispersion curves of leaky wave in SiO_2/49° Y-X $LiNbO_3$ structure under various boundary conditions.

Fig2 and fig3 is for shorted interface, fig4 and fig5 is for the situation of interface opened,

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surface shorted, fig6 and fig7 is the situation of both interface and surface opened. Since SiO_2 is nonpiezoelectric film, with interface shorted, we get same results whether surface is opened or shorted. From these figs, we can find that the leaky wave velocities and attenuation decrease with increase of kh. When kh>2, leaky mode will transfer to Rayleigh mode, attenuation becomes zero. When interface is opened, we find a dip of attenuation in the range 0<kh<0.4.

Leaky wave is coupled with surface waves and bulk wave. With depth increases, surface wave reduce and bulk wave increase. So on the surface, Leaky wave is similar to surface wave. Here, shear wave velocity in substrate Vt is 4085 m/s, in film Vtf is 3758 m/s, and Vtf<Vt, which is corresponding to the 'load' situation. In this situation, velocities decline with thickness increase. We also find that the film can suppress bulk wave, make attenuation smaller. In fig4, the boundary condition is that interface is opened and surface shorted. There are two effects in this case. One is surface 'short' effect, another is 'load' effect. When kh is very small, the surface short effect is the predominate one, so velocity increase. When kh=0.35, two effects is equally strong. When kh>0.35, the 'load' effect is the main one, so velocity declines. In all cases, velocities change from 4800 m/s to 4100 m/s, attenuations change from 0.0005dB/λ to zero. These characteristics is very useful in practical applications.

The electro-mechanical coupling coefficient can be calculated from fig2 to fig7, and are shown in fig8, where K2o is the electro-mechanical coupling coefficient of leaky wave for 49 Y-X $LiNbO_3$ substrate, K2 is that of leaky wave of SiO_2/49° Y-X $LiNbO_3$ structure. Curve I,II,III represent the following different situations: I) transducers are on the surface of SiO_2 and interface is opened. II) transduces are in the interface and surface is shorted. III) transducers are in the interface and surface is opened. In case I, electro-mechanical coupling coefficient K2 will decrease and go to zero quickly when film thickens kh increases. When transducers are in the interface between SiO_2 and 49° Y-X $LiNbO_3$, K2 will increase as kh increases and has maximum. As kh is in range of 0.4 to 0.8, the maximum is 1.08 times as large as K20 and is about 15%. This maximum is also two times as large as that of 128° Y-X $LiNbO_3$ which is the most widely used material for the SAW devices.

Considering the temperature dependence of elastic, piezoelectric, dielectric constant [8,9], we can get dispersion relations at different temperature by duplicating above calculations. The temperature dependence of ΔV/V (or temperature coefficient of delay) also can be obtained at different temperature and film thickness kh. The relationship between temperature coefficient of delay and film thickness has been given in fig9. The boundary conditions of fig10 and fig11 are the same as fig2, fig4 and fig6. Calculations are carried out at 25°C.

It can be seen that TCD changes from positive to negative as kh increases. In fig9, TCD=4 ppm at kh=2, in fig10, TCD=0 at kh=1.37, in fig11 TCD=0 at kh=1.53. These results show that zero TCD can be obtained with thinner film thickness in this structure. It means that thinner film is needed to compensate TCD for a specified frequency or with a specified film thickness we can get higher operating frequency at zero TCD point, while the electro-mechanical coupling coefficient is very large.

Fig12 gives TCD versus temperature as kh=2. Here, the boundary condition is interface shorted. When temperature changes from -40°C to 60°C, TCD increases. This is different from SiO_2/128° Y-X $LiNbO_3$ structure, TCD of which decreases with temperature increase. The range of TCD is 0.5 ppm to 4 ppm for SiO_2/49° Y-X $LiNbO_3$ structure. It is smaller than that of SiO_2/128° Y-X $LiNbO_3$ structure. This means that better temperature stability can be obtained.

CONCLUSION

In this paper we studied the leaky surface wave characteristics in SiO_2/49° Y-X $LiNbO_3$ structure. It is found that leaky mode still exists when deposited SiO_2 film in the range of kh <2. The attenuations are smaller than that of kh=0. In the range 0<kh<0.4, there is a zero point of attenuation. When transducers are in the interface, the electro-mechanical coupling coefficient increases to 1.08 times as large as that of kh=0. We have also found there exist several zero TCD points for SiO_2/49° Y-X $LiNbO_3$ structure. In the range -40°C<T<60°C, TCD changes less than 4 ppm. So better temperature stability can be expected. The thickness of film to obtain the zero TCD point is thin, less than one third of a wavelength. Hence, this structure is very useful in making high frequency, wide band, low loss and low temperature stable SAW devices. To verify the theoretical results, the experiments are needed.

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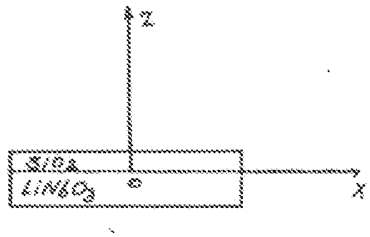


Fig 1

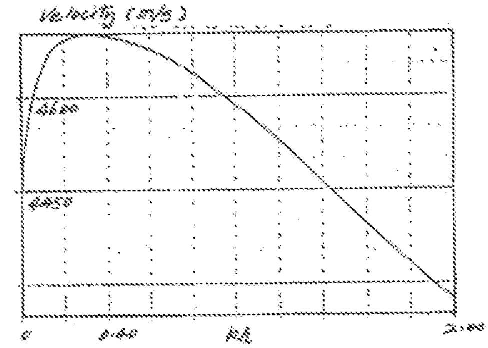


Fig 4

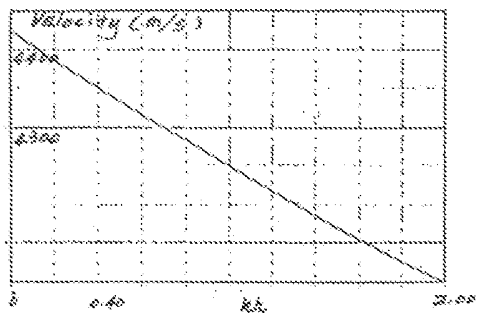
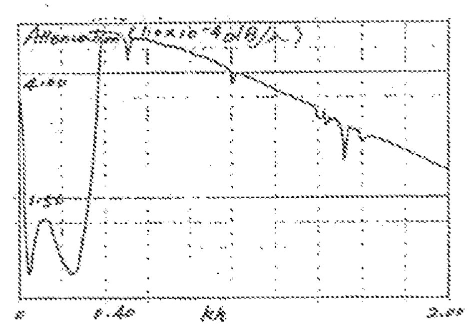


Fig 2



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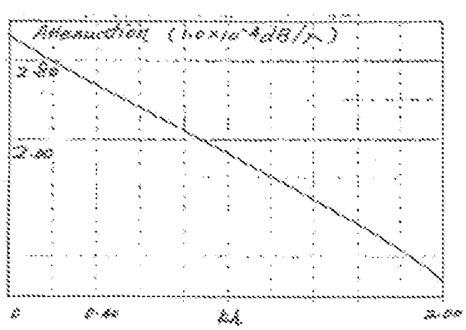

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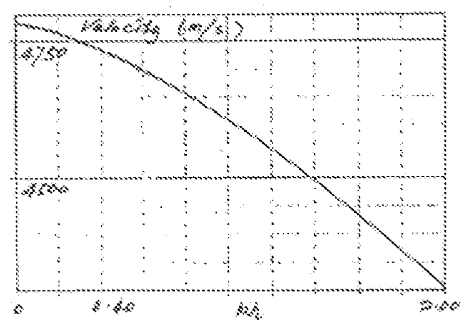


Fig 6

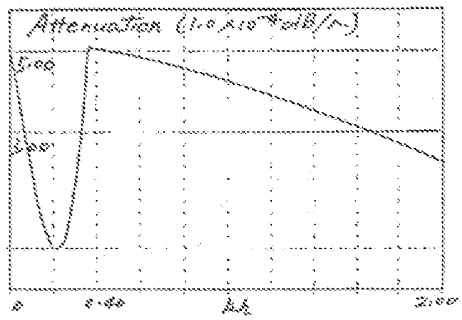


Fig 7

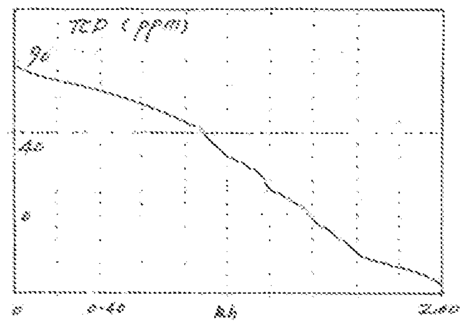


Fig 10

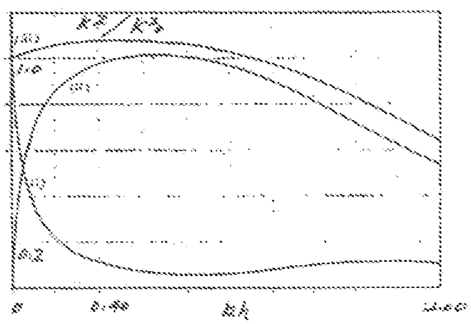


Fig 8.

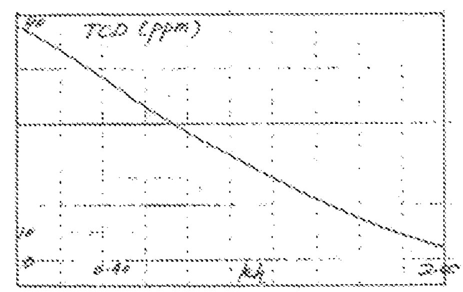
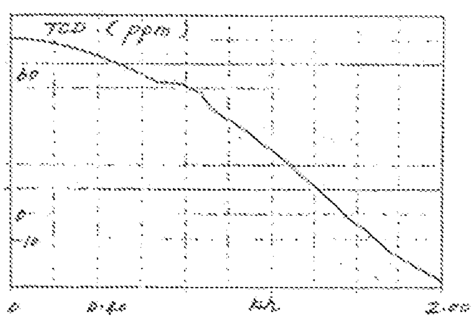


Fig 9



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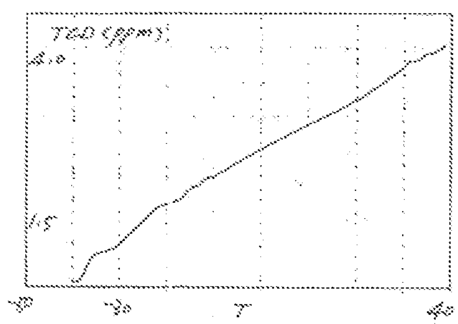

Fig 12